Paper presented in the IV Globelics Conference at Mexico City, September 22-24 2008

Globelics

Industrial clusters and the evolution of their knowledge networks: revisiting a Chilean case

Elisa Giuliani[*]
Martin Bell[**]

Abstract
Scholars of industrial clusters and networks have recently called for more research on network's chance over time. This paper contributes a further step along that path. It uses micro-level data based on the execution of a pair of identical studies in the main wine cluster in Chile in 2002 and 2006. Through the collection of social network data, it explores the role of a set of mechanisms of social interaction to explain the change in the cluster knowledge network. Two particular findings are important. First, in line with other network studies, we find that well-known micro-level mechanisms of social interaction, such as homophily, reciprocity and transitivity, do influence the formation of new knowledge linkages among cluster firms. Second, however, we find that these mechanisms seem not to work when firms have weak knowledge bases, as firms with a level of knowledge bases below a minimum threshold persist being completely cast out of the cluster knowledge network, in some cases even exiting the cluster. A more general finding of this study is the coexistence of a significant instability at the micro-level with meso-level stability in the structural properties of the intra-cluster knowledge network, in line with the idea of retention put forward by evolutionary economists to explain the path dependent nature of economic systems. Possible reasons for this and implications for further research are discussed.

Key words: Industrial cluster, knowledge networks, network evolution.

1 Introduction

It is only in fairly recent years that study of the knowledge networks of clusters or industrial districts has moved beyond fuzzy Marshallian perspectives about pervasive knowledge spillovers to examine more systematically what the structural and other characteristics of these networks actually are (e.g. Giuliani and Bell, 2005; Morrison and Rabellotti, 2005; Giuliani, 2007; Boschma and ter Wal, 2007). Aided by the use of formal network analysis methods, such work has moved further in a few instances to examine the relationships between the prevailing characteristics of knowledge networks at particular times and aspects of the innovative performance of clustered economic actors at those times – in the cases, for example, of a footwear district in southern Italy (Boschma and ter Wal, 2007), the producers of Broadway musicals (Uzzi and Spiro, 2005), or clustered wine producers in Chile and Italy (Giuliani, 2007). This paper contributes to a further step along that path by going beyond the analysis of static characteristics of cluster knowledge networks to examine their dynamics. It addresses theoretical and empirical questions about how and why these network characteristics change over time. It deals with the empirical aspect of that analysis by using a simple but surprisingly rare form of research design: repeating in almost identical form an earlier study of a cluster knowledge network – in this case the study of a cluster of wine producers in the Colchagua valley in Chile that was reported in Giuliani and Bell (2005).

[*] DEA, Facoltà di Economia, University of Pisa, Via Ridolfi, 10 – 56124 Pisa, Italy, E-mail: giulel@ec.unipi.it

[**] SPRU, University of Sussex. The Freeman Centre, University of Sussex, Brighton, East Sussex, BN1 9QE, UKE-mail: e.giuliani@sussex.ac.uk, E-mail: m.bell@sussex.ac.uk

Although we believe this is a novel step, it is not a step into totally uncharted territory. Two strands of previous work have converged to highlight the significance of a dynamic perspective on cluster knowledge networks. One is the strand of empirical research specifically on clusters and their knowledge networks that has led to questions about knowledge network dynamics, and in a few cases to initial empirical explorations. The other is a broader strand of thinking about the evolution of knowledge networks in economic geography (e.g. Glückler, 2007), sociology (e.g. Powell et al. 2005) and economics (e.g. Cowan et al. 2004).

The first strand can perhaps be traced to the growing recognition during the 1990s that the Italian industrial districts, that had once been the main source of understanding about spatially dense knowledge networks in clusters, were either coping poorly with technological and market changes in a globalizing world, or were having to alter key features of their former characteristics. In particular Guerrieri and Pietrobelli (2001), following the seminal work of Markusen (1996), speculated about ways in which cluster linkage structures might change through different 'constellations' in changing conditions (pp.15-16). Although these constellations were not specifically about knowledge networks, they encompassed knowledge-centred links. Along those lines, Ernst et al.(2001) argued that changing conditions called for the intensification of knowledge links that crossed cluster boundaries, leading to a shift in the balance between intra- and extra-cluster linkage structures (p. 139-140). Others have similarly questioned the dynamic stability of cluster knowledge networks shaped primarily by locational proximity (e.g. Iammarino and McCann, 2006), and they conclude that little knowledge is available about the dynamics of these patterns of knowledge interaction and "we need to understand exactly how they occur and change over time" (p.1030). More recently Boschma and ter Wal (2007) have made a similar call in their study of the relationship between knowledge network characteristics and innovation performance in a footwear district in Southern Italy. Moving beyond the insights they derived from their cross-sectional study, they highlighted the need for an "in-depth historical analysis of the evolution of the cluster" in order to interpret their results in particular, and more generally to "increase our understanding of whether geographical proximity matters or not in innovation processes in clusters" (p.197).

We are not aware of empirical work that has actually met these kinds of call for dynamic analyses in this area. There are however three that illustrate the value of such approaches, though they can only rather loosely be termed studies of 'clusters'. Uzzi and Spiro (2005) demonstrated how differences in the degree to which collaboration networks conformed to small world models affected the financial and artistic performance of the creators of Broadway musicals. This led them to conclude by echoing the general call for more work on processes of change: "the next step is the study of network dynamics. If small world networks can have positive and negative impacts, how do they arise and evolve?"(p. 498). Closer to our interest in networks associated with technological innovation, Fleming and Frenken (2007) examined the dynamics of knowledge networks among inventors in the Silicon Valley and Boston regions between 1975 and 2002. Lying yet closer to our interest in the relationship between the capabilities of innovation actors and the structure of their knowledge networks, Cantner and Graf (2006) analyse the dynamics of knowledge networks among inventors in Jena, Germany. They show that shared knowledge bases among inventors (similar areas of technological competence) are more important shapers of collaboration than are social relations in the form of previous collaboration partnerships.

Our own study in this paper contributes a step in that general direction. Our exploration of network dynamics rests on the execution of a pair of identical studies using methods of network analysis (Wasserman and Faust, 1994) in the same cluster in 2002 and 2006. This has created a unique relational dataset permitting detailed comparison over time – albeit over a relatively short period of only four years. The first study (Giuliani and Bell, 2005) demonstrated several structural features of the cluster knowledge network and it found strong relationships between different structural positions of firms in the network, and their knowledge bases. The second study in 2006 secured data to identify the same structural features and the same information about firms' knowledge bases.

The rest of the paper is organized as follows. In Section 2 we provide the empirical background for the study, including basic features of the Colchagua cluster in 2002 and 2006. Section 3 turns to the issue of dynamics, first outlining the conceptual framework we use, and then identifying the consequent hypotheses about how the Colchagua knowledge network would change after 2002. Section 4 summarises the methodology and Section 5 presents the empirical results. Section 6 concludes.

2. Background: the Colchagua cluster and its knowledge network

2.1 The Context: The Colchagua Valley cluster

The Colchagua Valley is one of the emerging wine clusters of Chile, located in the VIth Region, about 180 Km south-west of Santiago. At the time of the first survey, the wine industry in Colchagua Valley had just started to take off. New modern wineries had set up their operations in the cluster and there was a feeling that this was going to become one of the leading wine areas in the country, if not *the* leading area. Despite all the problems faced in rural Chile (inadequate infrastructure being the most important), private investors, mostly powerful Chilean families, were making considerable efforts, in some cases jointly with public institutions (e.g. CORFO)[1] to renovate and modernise the industry and catch up with the technological frontier. Already in 2002 some of the Colchagua wineries were as modern as those in other parts of the advanced world, and a substantial proportion of firms were using advanced technologies, employing skilled knowledge workers (oenologists and agronomists) and undertaking substantial experimentation in their vineyard and cellars. On the other hand, a considerable number were technological laggards.

In 2006 the cluster had changed quite strikingly. The most visible change was the improvement of the local infrastructure: new roads had been paved, a training institute specialised in wine production had been set up, and new arrangements were in progress for building up a research laboratory and a technology transfer office with the University of Talca. Also, a set of new marketing initiatives had been promoted, from the strengthening of the wine route to the set up of other new ventures connected to the flourishing local economy (promotion of local artisans, fairs, new restaurants, etc.) A number of new wine producers had been established in the area and, since 2005, local oenologists had arranged formal monthly meetings (*Reuniones de Enologos*) where views about each other's wines were exchanged and production methods compared.

The surveys in the two years covered the whole population of fine wine producers in the cluster – 32 firms in both cases. Table 1 indicates that there had been considerable change in several characteristics of these firms over the four years. Their increased size is particularly striking: nearly half of them (48 per cent) employed more then 100 people in 2006, compared with only 6 per cent in 2002. The proportion of firms with fewer than 20 employees had fallen to less than 10 percent, and the average size of firm had doubled from 55 to 110.

The number of firms established since 2000 increased from the original 6 to 10, as two that had been established in the 2000s exited the cluster before 2006 and 6 new entrants joined the cluster. This reflected part of a broader pattern of entry and exit to/from the cluster, with six firms exiting and six entering. There had been a considerable increase in the proportion of the firms that were foreign owned – rising to about one-third by 2006. This, however, was not directly the result of

[1] CORFO stands for Corporacion de Fomento and it is a Chilean Governmental institution that promotes industrial development.

entry and exit: all the entrants were domestic firms that established new businesses, and one of the six leaving firms was foreign owned. The increased foreign ownership arose as a result of the acquisition of incumbent businesses by foreign owned firms, and by the entry of one domestic incumbent into a joint venture partnership with a foreign owned firm.

Table 1 Firm characteristics in the two survey years

Characteristics of firms			2002 (N= 32)	Entry/Exit 2002 - 2006	2006 (N= 32)
(a)	**Size (number of employees)**				
	Small (1-19)	(%)	28		9
	Medium (20-99)	(%)	66		43
	Large (≥100)	(%)	6		48
	Average Number of Employees per firm	(number)	55.5		110.5
(b)	**Year of establishment**				
	Up to 1970s	(number)	6	-1	5
	During the 1980s	(number)	8	-1	7
	During the 1990s	(number)	12	-2	10
	During the 2000s	(number)	6	-2 + 6	10
(c)	**Firm entry and exit: 2002 - 2006**				
	Exit – Number of firms	(number)		6 (5 domestic)	
	Entry - Number of firms	(number)		6 (All domestic)	
(c)	**Ownership**				
	Domestic	(%)	81		66
	Foreign	(%)	19		34

2.2 The Baseline: The Colchagua Knowledge Network in 2002.

We present here a summary description of the structural characteristics of the Colchagua network as they were in 2002 – a necessary baseline for developing our propositions about the directions of change. Two preliminary comments should be noted. First, the detailed terms and definitions we use for a small number of the network features are slightly different from those used in Giuliani and Bell (2005). We use minor modifications that were introduced later in Giuliani (2005).[2] Second, because the summary description here necessarily precedes the detailed explanation of definitions and measurement methods in Section 4, we try to avoid technical network terminology at this stage.[3]

We examine three features of the cluster knowledge network: (i) the nature of firms' differing *cognitive positions* in the network; (ii) the existence and characteristics of different *cognitive sub-groups* in the network; (iii) the external knowledge interactions, look at the *external openness* of the network and the *cognitive roles of firms* that combine differences in their intra-cluster cognitive positions and their openness to extra-cluster sources of knowledge. These features of the 2002 network are outlined in Section 2.2.1. This is followed in Section 2.2.2 by a brief outline of the way

[2] These were introduced to improve clarity and make no significant difference to the basic features of the network reported in the earlier paper, or to comparison between the two dates.

[3] Readers seeking technical clarification at this stage can look ahead to Section 4.3.

these network characteristics were associated with and, we argued, shaped by the knowledge bases (or absorptive capacities) of the individual firms.

2.2.1 Key features of the cluster knowledge network

Three groups of features of the Colchagua knowledge network were examined: (i) the cognitive positions of individual firms, (ii) the structure of the intra-cluster knowledge network, and (iii) the external knowledge interactions.

(i) Firms' cognitive positions

This micro-level concept is concerned with the extent to which knowledge is transferred to or from firms in the cluster (their in-degree and out-degree centrality). Firms with knowledge inflows greater than outflows are termed *absorbers*; those in the reverse position are *sources*; those with approximately balanced positions are *mutual exchangers*; and those with very weak links in either direction are *isolates*. In 2002, a large proportion (44 per cent) of the firms fell into the last category. The second largest group (28 per cent) were the mutual exchangers. The remaining group were those with imbalanced cognitive positions, split almost evenly between sources (16 per cent) and absorbers (13 per cent).

(ii)The structure of the intra-cluster knowledge network

This meso-level concept was concerned with aggregate features of the network. Some of these features referred to differences in the density of interactions within and between sub-groups of firms. These structural formations may take different forms, for example, a constellation of several cohesive sub-groups that have dense interactions among their members and weak interactions with other subgroups. There are different ways through which the structure of a network can be measured (Wasserman and Faust, 1994). Building upon previous work (Giuliani and Bell, 2005), we look at the changes in the core-periphery structure, that was the predominant structure in the cluster in 2002. Firms in the *core* were highly interconnected among themselves, whereas peripheral firms had very loose linkages with the core firms (or none at all) and virtually no interconnections with other peripheral firms. The directions of knowledge relationships within this dual structure were also striking. Not only did core firms tend to transfer knowledge more often with other core firms (the density of links was highest for core-to-core relations), those firms were also primarily *sources* of knowledge for peripheral firms, though weak ones, and hardly ever acquired knowledge from peripheral firms. Even less did peripheral firms transfer or receive knowledge from each other. The structural characteristics of the network also include measures of distribution of linkages, to explore the degree to which this are evenly distributed across cluster firms.

(iii) External knowledge interactions

These interactions were examined in two ways; in terms of the general 'openness' of the network and in terms of the way external interactions combine with the intra-network cognitive positions (i.e. cognitive roles).

The external openness of the network

In general terms the Colchagua cluster was an 'open' knowledge system (Bell and Albu, 1999) as many of its firms had established linkages with external sources of knowledge: research and technology transfer institutes, universities, suppliers of materials and machinery, and also consultants – many of whom were foreign oenologists who played an important role in transferring frontier knowledge and techniques to Colchagua. However, the degree of openness varied widely across the firms, including firms with barely no extra-cluster linkages and those that were connected to a wide array of actors.

The cognitive roles of firms

These roles distinguish groups of firms in terms of the combination of their intra-cluster cognitive positions and their external openness. In principle the combination yields twelve categories of role, but it is more meaningful to see the Colchagua firms as falling into four groups covering ten of the possible roles.

(a) About one-third of firms (11) played the role we termed 'technological gatekeeper' (TG) – firms that combined a very high degree of openness to external knowledge sources with strong intra-cluster connectedness. These in turn fell into two sub-groups. The strong intra-cluster connectedness of about half of them (6) involved the reciprocal mutual exchange of knowledge with other cluster firms; while for the remainder (5) it involved the more imbalanced position of acting primarily as a source of knowledge for other firms.

(b) Another large group (10) were ' isolated firms' (IF) that combined weak linkages inside the cluster with very limited external openness.

(c) A smaller but important group (4) were classed as playing the role of 'external stars'(ES). They were extremely well connected to extra-cluster knowledge sources but, unlike the technological gatekeepers, they were very poorly linked to other cluster firms – being either totally disconnected from them (2) or acting (weakly) only as absorbers of other firms' knowledge, primarily from technological gatekeepers, without reciprocating the relationship.

(d) The remaining seven firms constituted a miscellaneous group of 'other' cognitive roles.

2.2.2 Firms' knowledge bases and the structure of the knowledge network

A central argument in the 2002 study was about the way in which these structural features of the Colchagua knowledge network were associated with, and shaped by, the knowledge bases of the individual firms. The term 'knowledge base' was used to refer to the quantity and quality of technological human resources in the firm and the extent to which it engaged in experimental activities to generate new knowledge.[4]

The underlying argument about how firms' knowledge bases would shape the structure of knowledge networks was linked to established ideas in the literature about, for instance, firms' absorptive capacities and their ability to exploit external sources of knowledge (Cohen and Levinthal, 1990), the importance of a certain degree of cognitive proximity for the formation of an intra-cluster knowledge community, and the importance of minimum thresholds of knowledge as a basis for engaging in knowledge interactions with other firms. In ways that were consistent with such arguments, the study found strong statistical associations between the structural features of the knowledge network and the knowledge bases of the cluster firms. In particular firms with stronger knowledge basis turned out to be those more connected to the intra- and extra-cluster knowledge system, while firms with weak knowledge bases seemed to be locked out of almost any interaction with the cluster knowledge system.

3 The Dynamics of Knowledge Systems: Concepts, Theory and Hypotheses

The previous study provided a snap-shot of the knowledge system at one point in time. We turn here to questions about change over time, necessitating the use of a different theoretical basis for

[4] These indicators are explained more fully later in Section 4.3.

the analysis (Section 3.1), leading to a set of hypothesis concerned specifically with ways in which key features of the knowledge system were likely to have changed between 2002 and 2006 (Section 3.2).

3.1. Underlying concepts and theory

To develop a conceptual framework that underpins the evolution of knowledge networks in geographical clusters of firms, we draw on a body of literature spanning sociology, psychology and evolutionary biology that has for a long time addressed issues about the formation and evolution of social networks. We do so selectively by considering only five mechanisms that have been used to explain the formation and evolution of networks, namely: *homophily*; *reciprocity*; *transitivity*; *preferential attachment* and *thresholding*. We explore each of them in the rest of the section.

3.1.1 Homophily

Homophily is the "tendency for friendships to form between those who are alike in some designated respect" (Lazersfeld and Merton, 1954, p. 23). Homophily expresses a certain degree of similarity, under different aspects of human being, like race, sex, education, attitudes and beliefs, etc. The pioneering study of Lazersfled and Merton (1954) and subsequent works (e.g. McPherson and Smith-Lovin, 1987; Rogers, 1983; Louch, 2000; McPherson et al., 2001) suggest that the existence of a commonality in certain characteristics favours the exchange of knowledge and ideas and makes communication smoother and more frequent.

The concept of homophily has been used by economists to explain the formation of inter-firm linkages – though using a different language to express the idea of inter-firm similarity. For example, there is a significant number of studies that explore the existence of a relationship between inter-firm 'cognitive proximity' and different types of inter-firm linkages (e.g. Arora and Gambardella 1990; Cohen and Levinthal, 1990; Hamel, 1991; Griliches, 1992; Mowery et al., 1996; Mowery et al. 1998; Lane and Lubatkin, 1998). These studies more or less all converge on the idea that similarity among firms plays an important role in shaping their communication. As Hamel (1991) points out: "*if the skills gap between partners is too great, learning becomes almost impossible.*" (p. 97)

3.1.2 Reciprocity

Reciprocity refers to behaviour in which one actor provides a favour to another (perhaps apparently altruistically) either in the expectation of receiving a favour in return or in response to a favour already received. Evolutionary biologists have found reciprocity to be an important influence on the selection and survival of some species over others, providing fascinating examples on how this occurs (Trivers, 1971).[5] The determinants and effects of reciprocity have been extensively studied in human behaviour by psychologists and sociologists (e.g. Gouldner, 1960) and this behaviour has been recently considered to influence market and non-market transactions among firms and/or their employees (e.g. Granovetter, 1985; von Hippel, 1987; Bouty, 1990; Fehr and Gachter, 2000; Schrader, 1991). For example, economists use the idea of reciprocity to explain the fact that firms transfer know-how to other firms via informal channels, apparently without compensation - subsequent reciprocation of the transfer being the expected pay-off (von Hippel, 1987; Schrader, 1991). The key point about reciprocity is that it stabilises relationships over time.

[5] See for example, Trivers' (1971) account of the relationship between the cleaning symbioses in fishes.

3.1.3 Transitive closure and the formation of cohesive subgroups

So far we have mentioned mechanisms that lead to the formation and persistence of linkages between *two* individuals (i.e. homophily and reciprocity), here we discuss instead the social mechanisms for the formation of linkages between *three or more* individuals, which lead to the formation of a given "structure" in a network. A key starting point here is what is known in social psychology as "balance theory" (Heider, 1958), which suggests that an individual establishes a new linkage with a third one on the basis of whether, the individuals she/he is already connected to, have positive feelings about (and are themselves connectedto) this third person. Basically, the idea is that an individual perceives a sort of psychological pressure from their her/his direct contacts (e.g. friends) and is induced to choose new contacts in a way that preserves a sort of consistency and harmony (or balance) within the social group she/he is part of. The concept of balance is often named 'transitivity' and it has been extensively studied especially in friendship networks (e.g. Holland and Leinhardt, 1971; Gibbons and Olk, 2003), as a means of explaining the formation of cohesive subgroups (e.g. *cliques*).

3.1.4 Preferential attachment

The concept of preferential attachment has been increasingly used in recent years to demonstrate that most large networks display scale-free distributions (Barabasi and Albert, 1999; Barabasi et al., 1999). This means that linkages are not evenly distributed across the population of network members but they are concentrated in the hands of a few 'hubs'- i.e. nodes with an extraordinarily high number of linkages. Example of this type are found in the connectedness of the web, where a few well-connected hub nodes - one like Google portal – stand out. Other networks display power-law properties, such as the protein interaction networks, the metabolic networks for eukaryotes and bacteria, movie-actor networks, and the citation networks (Amaral et al., 2000; Goh et al., 2001).

The most interesting aspect of this property is that it may illuminate the evolution of networks over time. In effect, preferential attachment is considered to be the result of a 'rich get richer' phenomenon, so that the most connected nodes become more connected over time. This occurs when actors, who have to decide whom to link with, express a preference to connect to the nodes that already have many links. The implication of this mechanism for the growth of the network is that it may foster inequity and leave poorly connected nodes to become more marginal over time – unless they have or acquire the necessary knowledge-bases to connect with the strongly linked firms. This raises another issue that may affect change in the position of poorly connected nodes.

3.1.5 Thresholding effect

We consider *thresholding* as a very selective way to form new linkages in given contexts, which occurs only if the interacting parties possess some valuable characteristics over a certain threshold (e.g. status, power, wealth, skills, etc.). [6] In contrast, actors with below-the-threshold characteristics are less likely to form linkages at all. Masuda and Konno (2006) consider thresholding to be a determinant in the formation of VIP-clubs or other elite circles, where a hierarchy exists that selects new entrants according their characteristics.

The point emphasised here is that, in given contexts, individuals who are below a certain threshold of given characteristics establish linkages with neither those that are above the threshold *nor* those

[6] Please note that this is different from the established concept of "threshold models" of collective behaviour (Granovetter, 1978; Valente 1996) that postulates that an individual engages in a behaviour based on the proportion of people in the social system already engaged in the behaviour. In this paper, the threshold is established by the internal characteristics of actors, not by their linkages.

that have similar sub-threshold characteristics. A significant example is that of homeless people, who share similarly fragile and precarious conditions but seldom interact with each other (Rokach, 2004; Hersberger, 2007). The same applies to people with psychological disorders. We also find such under-socialised behaviour in the different context of clusters in developing countries where poor artisans or entrepreneurs facing similar market and credit constraints may not only be disconnected from more favourably positioned artisans and entrepreneurs, but also cheat each other, instead of collaborating and exchanging critical information (Visser, 1999). This is an active policy issue in many developing countries (UNIDO, 2004).

These studies suggest that strikingly resource-poor actors are less likely to form linkages even with potentially homophilous actors, possibly because they lack an internal push or an inherent motivation to do so, or because they believe they cannot gain much from those who have similarly poor characteristics. Accordingly, it is plausible that, in such resource-poor conditions, the conventional mechanisms of social network formation – homophily, reciprocity, transitivity, etc. – may not operate as we would expect.

3.2. Knowledge network dynamics in Colchagua: key hypotheses

3.2.1 Persistence and change of cognitive positions

In developing hypotheses about the persistence and/or change of cognitive positions in the intra-cluster knowledge network we initially use two of the mechanisms discussed in Section 3.1, namely homophily and reciprocity. First, firms in the cluster will tend to exchange knowledge with firms that have equally advanced knowledge bases (homophily) and will tend to move towards such relationships. Second, more stable linkages will be those that are reciprocated. Consequently we argue that balanced cognitive positions – i.e. mutual exchangers – will be relatively persistent over time, and conversely the imbalanced (less reciprocated) cognitive positions – i.e. sources and absorbers - will be more transitory as firms in those positions seek to establish reciprocal ties and more stable relationships. Hence, as time passes, we expect imbalanced cognitive positions to become more balanced.[7] On this basis the following hypothesis is formulated:

> **Hypothesis 1** Mutual exchangers are a persistent cognitive position, whereas imbalanced cognitive positions (sources and absorbers) are more transitory.

A third mechanism, thresholding, comes into play in explaining what may happen to firms that are isolated in the intra-cluster knowledge network. In previous work (Giuliani and Bell, 2005 and Giuliani, 2007) we argued that the knowledge base of some firms in clusters may be so low that it neither offers anything of value to justify the emergence of linkage with others nor provides a capacity to acquire and exploit knowledge that others may have. Consistent with that, we found that, below a given knowledge base threshold, firms were likely to be ‘isolated’ in the intra-cluster knowledge network. Since, isolated firms are much less likely than others to strengthen their knowledge bases, we argue that this position is either persistent over time or will lead firms to exit the industry, as in the following hypothesis:

> **Hypothesis 2** Isolated firms in the intra-cluster knowledge network are likely to persist in that same cognitive position or to exit the industry.

7 This does not imply that imbalanced cognitive positions will tend to disappear. For example, they might be common in new entrants to the cluster.

3.2.2. Persistent cohesive subgroups in the intra-cluster knowledge network

Intra-cluster knowledge networks can be structured in many different ways, and we argue here that the particular forms of structure depends on the mechanisms that operate at the micro-level that leads to the evolution of cohesive subgroups. In particular, in this section we argue that, in addition to homophily and reciprocity, the evolution of intra-cluster knowledge networks may be influenced by transitivity, preferential attachment and thresholding.While homophily and reciprocity favour the strengthening of balanced cognitive positions – as discussed in Sections 2.2.1 and 2.2.2 – transitivity leads to the formation of cohesive sub-groups of firms (e.g. different types of cliques). However, our idea is that these structures will not necessarily lead to an evenly distributed connectivity of firms – i.e. not all firms will be part of cohesive sub-groups in the same way. In fact, preferential attachment (rich-get-richer) and thresholding will operate as selective and differentiating mechanisms. Preferential attachment is likely to strengthen the position of the most connected nodes, leading to self-reinforcement mechanisms of those firms which are in the 'core' of the intra-cluster knowledge network (see Section 3.1.4); whereas thresholding will act as a sort of centrifugal force, keeping poorly connected nodes in the periphery of the network. For this reason, the following hypothesis is elaborated:

> **Hypothesis 3:** The core-periphery structure if 2002 will persist as core firms in the intra-cluster knowledge network remain in the core, while peripheral firms remain in the periphery.

3.2.3. External Openness: persistence and change among Gatekeepers and External Stars

We explore here the persistence and change of cognitive roles (described in Section 2.2.1). However, we restrict our focus to only the most significant roles that relate to external openness, namely those of technological gatekeeper (TG), external star (ES) and isolated firm (IF). Our prediction is that TG firms will persist in that role more than firms acting as external stars. Recall that technological gatekeepers are connected both at the intra-cluster level (as sources or mutual exchangers) and externally. In line with Hypothesis 1, the chances are that TG firms will persist in this position because the TG that are mutually exchangers at the local level, are likely to persist in that position, while sources may transform into mutual exchangers. As we do not expect a significant change in the external openness of these firms, we argue that TG is likely to be a fairly stable role . The following hypothesis is therefore formulated:

> **Hypothesis 4**: Technological gatekeepers play a persistent cognitive role.

In contrast, external stars have strong connections to extra-cluster source of knowledge while they are either absorbers or isolates in relation to the intra-cluster knowledge network. On the one hand, we expect some of the ESs (the absorbers) to become TGs, shifting from an unbalanced cognitive position to a more balanced one (mutual exchanger), because of homophily and reciprocity. On the other hand we cannot advance any hypothesis about the locally isolated ESs. In this case, it is possible that ES firms face constraints that inhibit spontaneous socialisation and network formation. For example such a firm may have a mandate not to connect to local firms – as it may occur with subsidiaries of foreign firms. . It is equally possible that locally isolated ESs will become progressively more embedded in the intra-cluster knowledge network and tend to behave as TGs. For all these reasons, we consider the role of ES to be transitory and subject to changes:

> **Hypothesis 5** External Star play a transitory cognitive role.

Finally, we argue that Isolated Firms, which have poor linkages both at the extra- and intra-cluster level, will persist in that cognitive role or will exit the industry, as a result of the centrifugal force of thresholding:

> **Hypothesis 6** Isolated firms both at the intra- and extra-cluster levels are likely to persist in that same cognitive role or to exit the industry.

4 Methodology

4.1. The Data

This study is based on micro level data, collected at the firm level in the Colchagua Valley cluster at two points in time: 2002 and 2006. The interviews were carried out following exactly the same procedure: the first author of this paper undertook all the interviews in both periods, the interviews were carried out at the same time of the year (August-September) and they were based on nearly the same structured questionnaire.[8] In both years, interviews were carried out with the firms' skilled workers (i.e. oenologists or agronomists) in charge of the production process at the firm level and they lasted an average of one and a half hours. The survey was based on the population of fine wine producers in the cluster in the two years which is 32 in both cases, with firm entry and exit over the period being balanced: six firms leaving and six starting up.

An important part of the interviews collected relational data to map the intra-cluster knowledge network.This kind of data was collected through a roster recall method (Wasserman and Faust, 1994), which means each firm was presented with a complete list (roster) of the other wine producing firms in the cluster, and was asked questions related to the transfer of innovation-related knowledge. The questions specifically addressed problem solving and technical assistance because these activities involve some effort in producing improvements and change within the economic activity of a wine firm. So, the knowledge transferred (in or out) is normally the reply to a query on a complex problem that has emerged and that the firm seeks to solve.[9] The resulting network data are expressed in matrix form: each cell in the matrix reports the existence of knowledge being transferred from firm *i* in the row to firm *j* in the column. The same questions and procedure in gathering relational data were adopted in 2002 and 2006.

4.2 Analysis: Testing the hypotheses

The analysis of the data is in two parts. The first, covered in this section, tests the hypotheses about persistence and change in selected characteristics of the intra-cluster knowledge network. The methods used are summarised in Table 2. Part (A) of the table focuses on Hypotheses 1 and 2. These are tested by examining how firms have changed their cognitive positions in the network ('sources', 'absorbers', 'mutual exchangers' and 'isolates') between 2002 and 2006, and the measures for these are shown.

Part (B) reports the measures and methods used to test Hypothesis 3 about the persistence of firms in cohesive subgroupsin the intra-cluster network in the two periods. This comparative analysis of the structure of the two networks has been undertaken in three ways (i) by using a simple graph-

8 Some slight modifications were made to the questionnaire used in 2006 but changes did not affect the key variables used for this paper.

9 The relational data was based on responses to the following two questions: (Q1) "If you are in a critical situation and need technical advice, to which of the local firms mentioned in the roster do you turn?" and (Q2) "Which of the following firms do you think have benefited from technical support from this firm?". Further details can be found in Giuliani and Bell (2005) and Giuliani (2007).

theoretical indicator, the network density (*ND*), that measures the intensity of inter-firm networking in the clusters; (ii) by comparing the distribution of the degree centrality of firms in the intra-cluster knowledge networks using the Gini coefficient as an indicator, and (iii) by applying core-periphery models to fit the network data (Borgatti and Everett, 1999).

Finally, Part (C) reports the measures and methods used to test Hypotheses 4-5 about the persistence of cognitive roles. This analysis has required the definition of different cognitive roles by bringing together data concerning the external openness and the 'cognitive position' of firms. Combining these aspects, we identified different learning patterns within the cluster, corresponding to 10 different types of 'cognitive roles' – three of which are considered for the test of hypothesis: Technological Gatekeepers (TG), External Stars (ES) and Isolated Firms (IF).

Table 2 Methods of analysis and measures

A.

Hypothesis 1: Mutual exchangers are a persistent cognitive position, whereas imbalanced cognitive positions (sources and absorbers) are more transitory.

Hypothesis 2: Isolated firms in the intra-cluster knowledge network are likely to persist in that same cognitive position or to exit the industry.

Analysis of the cognitive positions of firms in the cluster and their change from 2002 to 2006	
(i)	**Cognitive Positions:** - Sources (S): firms with an in/out degree centrality ratio < 1 - Absorbers (A): firms with an in/out degree centrality ratio > 1 - Mutual exchangers (ME): firms with an in/out degree centrality ratio = 1 Isolates (I): firms with in- and out-degree centralities approximating to 0
(ii)	Graph theoretical methods were adopted to measure different dimensions of the 'centrality' of firms communication patterns, and more generally their cognitive positions in the cluster. **Outdegree Centrality Index:** measures the extent to which technical knowledge *originates from* a firm to be used by other local firms. The indicator is computed on *dichotomous* data that reflect the presence/absence of a linkage **Indegree Centrality Index:** measures the extent to which technical knowledge is acquired by/*transferred to* a firm from other local firms. Again the indicator is computed on *dichotomous* data.

B.

Hypothesis 3: The core-periphery structure if 2002 will persist as core firms in the intra-cluster knowledge network remain in the core, while peripheral firms remain in the periphery.

Analysis of cohesive subsets in the intra-cluster knowledge network and their persistence or change from 2002 to 2006	
(i)	Comparison of **network density.** Network density (*ND*) is defined as the proportion of possible linkages that are actually present in a graph. *ND* is calculated as the ratio of the number of linkages present, *L*, to its theoretical maximum, $g(g\text{-}1)/2$, with g being the number of nodes in the network (Wasserman and Faust, 1994): $ND = L\ /\ [g(g\text{-}1)/2]$
(ii)	Comparison of knowledge networks with respect to the Gini coefficient applied to **Degree Centrality** (undirected, dichotomous).
(iii)	**Core-periphery models**: core-periphery analysis allows the identification of a cohesive subgroup of core firms and a set of peripheral firms that are loosely interconnected with the core (Borgatti and Everett, 1999).

C.

Hypothesis 4: Technological gatekeepers play a persistent cognitive role

Hypothesis 5: External Star play a transitory cognitive role

Hypothesis 6: Isolated firms, both at the intra- and extra-cluster levels, are likely to persist in that cognitive role or to exit the industry.

Analysis of the changes in the composition of cognitive roles, particularly of the groups of TG, ES and IF from 2002 to 2006	
(i)	**Technological Gatekeeper (TG):** when the cognitive position in the cluster is that of source or mutual exchanger and the degree of external openness is higher than average.

External Star (ES): when the cognitive position is that of an absorber or an isolated firm and the external openness is higher than average.

Isolated Firms (IF): when the cognitive position is that of an isolate and firms have lower than average external openness.

(ii) **External Openness:** the number of linkages with extra-cluster sources of knowledge. See Giuliani and Bell (2005).

Note: Network measures are computed using UCINET 6.51 (Borgatti et al., 2002).

The indicators in Table 2 are calculated for 2006 on the basis of the firms present in the cluster at the time, including entrants since 2002. The characteristics of the cluster network as a whole are identified and compared on the basis of the full set of firms present at each date; but changes in network positions/roles refer to firms that were in the cluster in 2002 and do not include the new entrants that were present in 2006.

4.3 Network evolution: the underlying social mechanisms

The second part of the analysis explores more generally the validity of our broader arguments (Section 2.2) about the role of social mechanisms in contributing to change/stability in the structural properties of the intra-cluster network. To examine the effects of homophily, reciprocity, transitivity, and preferential attachment we use a class of stochastic actor-oriented models for network evolution proposed by Snijders (2001), employing Stocnet SIENA as the software (Snijders et al. 2007; http://stat.gamma.rug.nl/siena.html).

Furthermore, we examine the thresholding-effect with respect to one key variable: the knowledge base (KB) of the firms, which we have associated to the formation of knowledge linkages in previous work (Giuliani and Bell, 2005; Giuliani, 2007). As in Giuliani (2007) we measure the KB as a Principal Component of three correlated variables: (i) the number of technically qualified personnel in the firm and their level of education and training (Human resources), (ii) the experience of technically qualified personnel – in terms of months in the industry (Months of experience); and (iii) the intensity and nature of the firms' experimentation activities (Experimentation intensity). The variable thus has 0 as a mean value and 1 as standard deviation.

5. Changing network characteristics: Empirical results

We report on the empirical analysis in two parts. First, we present the result of testing the specific hypotheses developed above (5.1). Second, we report the results of our exploration of the significance of the social processes that we suggest underlie the hypothesised changes in network structure (5.2).

5.1 Tests of Hypotheses

5.1.1 Cognitive positions

In line with our original findings, firms do not participate in the intra-cluster knowledge network in a homogeneous way, and the cluster continues to be populated by firms with different cognitive positions. Table 3 shows how the distribution of firms between these positions changed in two important ways between 2002 and 2006: (i) the number of 'mutual exchangers' increased considerably (from 28 per cent to 48 per cent); and (ii) the number of 'isolates' decreased in a similar way (from 44 to 24 per cent). In contrast, the number of firms holding imbalanced cognitive positions changed only marginally (the number of 'sources' falling slightly to 12 per cent and 'absorbers' barely changing at 14 per cent).

Table 3 Cognitive positions in 2002 and 2006

Cognitive positions in the cluster	Percentage 2002*	Percentage 2006*
Sources - firms with an In/Out degree centrality ratio > 1	16%	12%
Mutual exchangers - firms with an In/Out degree centrality ratio = 1	28%	48%
Absorbers - firms with an In/Out degree centrality ratio < 1	13%	14%
Isolates - firms with In and Out centralities approximating to 0	44%	25%

Note (*): The number of firms for each year is 32, which corresponds to the population of firms in each year.

Hypothesis 1, resting on an argument about the power of reciprocity in shaping firms cognitive positions, suggests that mutual exchangers would be the most persistent cognitive position, whereas imbalanced cognitive positions (sources and absorbers) would be more transitory, tending to shift towards mutual exchanger positions. The results in Table 4 support this hypothesis: (i) mutual exchangers are a very persistent cognitive position (90 per cent of firms in that position in 2002 remained mutual exchangers in 2006); (ii) in contrast, much smaller proportions of the firms with imbalanced cognitive positions in 2002 persisted and, when they shifted, they tended to move towards the more balanced mutual exchanger position (60% and 50% in the case of sources and absorbers respectively).

The data also provide strong support for Hypotheses 2. A significant proportion of ‘isolates’ in 2002 (36 per cent) persisted in that position in 2006, and a larger proportion (44 per cent) left the business and the cluster. Only 20 per cent of them (3 firms) improved their cognitive position becoming more connected to the intra-cluster knowledge network as ‘absorbers’ or in one case as a ‘mutual exchanger’.

Table 4 Changes in the cognitive position of firms from 2002 to 2006

Cognitive positions in the cluster	Persistence in the same position*	Change towards*:				
		Source	Mutual Exchanger	Absorber	Isolates	Exit the cluster
Sources	40%	-	**60%**	**0**%	0%	0%
Mutual exchangers	**90%**	0%	-	0%	10%	0%
Absorbers	25%	25%	**50%**	-	0%	0%
Isolates	**36%**	0%	6%	14%	-	**44%**

Note (*): The percentages are calculated on the population of firms present in 2002 (32). It thus includes incumbents of 2006 but not new entrants.

5.1.2 The structure of the intra-cluster knowledge network

As shown in Table 5, the intra-cluster knowledge networks differ considerably in their density values: 0.0938 in 2002 and 0.2301 in 2006. In principle, such a large increase in the overall number of links in the network might be interpreted as a sign of major inclusion of cluster firms into the knowledge network, possibly reflecting a much more even diffusion of knowledge among cluster firms. However Table 5 also shows that the the value of the Gini coefficient of actor-level degree centrality in the intra-cluster network has not changed. That is, the density has increased but the distribution of linkages has remained exactly the same. Thus, despite the increased overall number of linkages, the topological features of the network have not changed.

Table 5 Overall structural indicators of the intra-cluster knowledge network in 2002 and 2006*****

	2002	**2006**
Density	0.0938	0.2301
GINI Coeff. for firms' degree centrality	0.45	0.45

Note (*): Density and GINI are calculated on the network formed by the population of firms in each year.

To explore this result further we compare the structural form of the intra-cluster network in 2006 and 2002 (Table 6). We find not merely that the network maintained its core-periphery structure, but that this became more pronounced (the final fit increased from the original 0.433 to 0.861 in 2006). In particular, the density of core-to-core relations increased (from 0.341 in 2002 to 0.864 in 2006), while peripheral firms persist in being poorly connected to the core and especially to other peripherals (periphery-to-periphery density is 0.032 in 2002 and 0.045 in 2006). Thus the structural features that were present in 2002 – with a cohesive core and a loose periphery - persisted over time. This also helps to explains why, despite the increase in network density, the linkages continued to be distributed in the same uneven way.

Table 6 Density of linkages within and between core and peripheral groups in 2002 and 2006[10]

2002	**The Density of Linkages*** (Knowledge transfer from row to column)		**Final Fit**
	Core	**Periphery**	
Core ***(n_C=12)***	0.341	0.096	**0.433**
Periphery ***(n_P=20)***	0.054	0.032	
2006	**Core**	**Periphery**	
Core ***(n_C=12)***	0.864	0.230	**0.861**
Periphery ***(n_P=20)***	0.206	0.045	

Note (*): The density of Core-Periphery is calculated considering the network formed by the population of firms in each year.

Moreover, as shown in table 7, there was very limited mobility of individual firms between the core and peripheral groups: 75 per cent of the firms that were in the core in 2002 remained in the core in 2006; 60 per cent of peripheral firms remained in the periphery and 30 per cent left the industry (30%), with only a tiny number moving to become part of the core (10%). This supports Hypothesis 3.

[10] The densities in Table 6 are calculated on dichotomous data. Giuliani and Bell (2005) measured it in valued data, which explains the differences in the 2002 data of the table.

Table 7 The persistence of the core-periphery positions from 2002 to 2006

	Persistence*	Change* (Core to Periphery Or Periphery to Core)	Exit*
Core	**75%**	25%	0%
Periphery	**60%**	10%	**30%**

Note (*): The percentages are calculated on the population of firms present in 2002 (32). It thus includes incumbents of 2006 but not new entrants.

5.1.3 External Openness and cognitive roles

In general terms the Colchagua Valley cluster can be described as an ‘open’ knowledge system as many of its constituent firms have established linkages with external sources of knowledge. This increased between 2002 and 2006 as a larger proportion of firms established links with many external sources of knowledge both at the national and international levels (e.g. universities, consultants, clients, suppliers, etc.). In this section we examine how individual firms combined their external openness and their ‘cognitive position’ within the intra-cluster knowledge system. In our previous study (Giuliani and Bell, 2005). We combining these two aspects to identify ten different modes of technological learning by firms in the cluster (different types of ‘cognitive role’). Here we focus selectively on only three key cognitive roles in the cluster knowledge system, namely the Technological Gatekeepers (TGs), Isolated Firms (IFs) and External Stars (ESs). The number of Technological Gatekeepers had barely changed (accounting for 38 per cent of firms in 2006 and 35 per cent in 2002). In contrast, the number of Isolated Firms decreased by about 30 per cent (accounting for 22 per cent of all firms in 2006, but for (31 per cent in 2002). . The number of External Stars, a cognitive role that we found particularly interesting in 2002, had fallen even more sharply (accounting for 16 per cent of the cluster firms in 2002, but for only 6 per cent in 2006.

In order to test Hypotheses 4-6, Table 8 reports the mobility of individual firms in these three cognitive roles between the two dates. As predicted by Hypothesis 4, TGs are the most persistent cognitive role of all: 64 per cent of firms in that role in 2002 remained in it in 2006. . Only two other firms altered their role in a significant way by becoming externally isolated. In contrast, with respect to Hypothesis 5, it is striking that none of the ESs persist in that cognitive role and moved in different directions: one became more embedded at the local level and transformed into a TG, while the remaining three either moved to more poorly connected roles or left the business. Finally, with respect to Hypothesis 6, 50 per cent of the isolated firms (IF) persisted in being completely isolated and 30 per cent left the cluster. Only one became slightly more connected at the intra-cluster level. These patterns of persistence (TGs), transition (ESs), and persistence or exit (IFfs) are consistent with Hypotheses 4, 5 and 6.

Table 8 The change of cognitive roles from 2002 to 2006

	Persistence*	Changes towards*:				
		TG	**ES**	**IF**	**Other roles**	**Exit**
TG	**64%**	-	0%	0%	**36%** (2 EC-ME 2 EI-ME)	0%
ES	0%	25%	-	0%	50% (1 EC-A 1 EI-S)	**25%**
IF	**50%**	10%	0%	-	10% (1 EI-A)	**30%**

Note (*): The percentages are calculated on the population of firms present in 2002 (32). It thus includes incumbents of 2006 but not new entrants.

5.2 The role of entry and exit

As noted earlier, the results reported above take no explicit account of the entry of firms, while it only briefly refers to exitors. A question therefore arises about whether the characteristics of the network were significantly influenced by the relative entry and exit patterns. Two initial points should be noted. First, the identical number of firms in the two groups is a coincidence and not the result of new entrants simply taking over the businesses of exiting firms. In all but one case the new entrants started up by creating new business units in new areas of the Colchagua Valley. Second, there was little difference between entrants and exiting firms in their foreign/domestic ownership. The overall incidence of foreign ownership of cluster firms did rise a little but, as noted earlier, this involved change in the ownership of incumbent firms and, with the exception of one exitor, both groups of firms were domestically owned.

However, as shown in Table 9, there were considerable differences in other characteristics of the two groups. The new entrants were on average relatively large – twice the size of the exitors in terms of employees. There were more striking differences in terms of the firms' knowledge bases: (i) the new entrants employed more than five times as many knowledge workers; (ii) the gap in terms of knowledge workers as a proportion of all employees was even greater - the new entrants' level also being more than twice that of the incumbent firms; and (iii) the new entrants' average level of experimentation intensity was more than seven times the level in exiting firms and marginally higher on average than in the incumbents.

Table 9 Characteristics of New Entrants and Exiting Firms

	Exitors (N=6)	**Incumbents** (N=26)	**Entrants** (N=6)
(a) Size			
Average Number of employees per firm	26	96	57
(b) Knowledge Base			
Average number of knowledge workers per firm	0.57	5.0	2.83
Average number of knowledge workers/employee	0.03	0.08	0.19
Average experimentation intensity	0.33	2.00	2.33
(c) Location in Network structure			
Number of firms in the Core	0		1
Number of firms in the Periphery	6		5
(d) Cognitive Positions (number of firms)			
Sources	0		1
Mutual Exchangers	0		2
Absorbers	0		1
Isolates	6		2
(e) External Openness			
Average index	5.4		14.8
(f) Cognitive Roles (number of firms)			
Technological Gatekeeper	0		1
External Star	1		1
Isolated Firm	3		2
Other	2		2

Given the relationship between the strength of firms' knowledge bases and their location in the core-periphery structure of the knowledge network (Giuliani and Bell, 2005, 57-58), one might have expected these considerable differences between the knowledge bases of entrants and exitors to have influenced the balance between the core and peripheral groups. However, this was not the case. New entrants did have some influence on the increased density of the overall network, but the large change in this aspect of network structure (Table 5) mainly resulted from the fact that the density for incumbents more than doubled from a relatively high base in 2002. Reflecting this limited connectedness of the new entrants, only one of them joined the core group and the other five simply replaced exitors that had been located in the periphery of the network – (c) in Table 9.

But despite their limited connectedness, the new entrants were not totally concentrated in the cognitive position of Isolates, as the exitors had been. Instead, they were distributed across all the categories, with half of them being in the more active positions of Sources and Mutual Exchangers – (d) in Table 9. They were also nearly three times as open to external sources of knowledge as the exiting firms had been, with two of them occupying the roles of Technological Gatekeeper and External Star, and only two being Isolated Firms – (e) and (f) in Table 9. Other more qualitative information about these firms suggests that almost all of them were much more technologically and commercially dynamic and aggressive than the exiting firms and many of the incumbents.

Our overall view about the role of entry and exit is therefore twofold. First, the combination of both has played an important role in upgrading the general knowledge-base of the cluster, alongside the upgrading process that has been most commonly emphasised in conventional cluster studies: strengthening of the knowledge-bases of incumbent firms. Consequently, the fact that new entrants have distinctly stronger knowledge bases than exiting firms might be expected to have helped to shape the extra- and intra-cluster knowledge interactions. Second, however, that did not happen in this case. Most of the new entrants did not drop immediately into positions and roles in the cluster knowledge network that would have been expected in the light of their knowledge bases and emerging innovative profiles. We speculate that a network-related learning process was probably under way as, for instance, potential dyad partners learned about their convergent characteristics before homophily could 'work' as a network shaping force.

5.3 An analysis of the social mechanisms of network change

In this section we explore the underlying social mechanisms that underpin the evolution of the intra-cluster knowledge network. As anticipated in Section 4.3, we will test whether the change in the network has been due to the effect of homophily, reciprocity, transitivity and preferential attachment (5.3.1). Further, we also explore the thresholding-effect in Section 5.3.2.

5.3.1 The role of homophily, reciprocity, transitivity and preferential attachment

Table 10 reports the results of the stochastic actor-oriented estimation. Parsimony is required when using this class of models, so, first, we tested for the presence of network effects, namely reciprocity, transitivity (Model 1) and preferential attachment (Model 2) and, second, we added actor's effect homophily (Model 3). Let us clarify that the rate parameter is positive and significant in all models indicating that there has been a significant change in the formation of new ties. Also, among the network effects, the negative and significant coefficient of density indicates that firms tend not to establish knowledge linkages with just any other firm in the cluster (Steighlich et al. 2007).

In Model 1 we found reciprocity to be a very strong and significant driver of new tie formation, as the coefficient is 2.5 with a standard error of 0.27. Meanwhile, we also find that there is a certain tendency towards transitive closure in the network, although this effect is not as strong as the one found for reciprocity (the coefficient is 0.1732 and the s.e. 0.0304). This means that some parts of the knowledge networks tend to grow by connecting to firms which are already tied to each other, thus forming a triplet of firms, but the strongest driver of new tie formation is the search of dyadic reciprocity.

In Model 2, we add the effect of the 'activity of alter', which tests for preferential attachment. This means that it tests whether the formation of a new linkage is more likely for actors that have already more out-going linkages, which in this study means actors that transfer more knowledge to other firms of the network. As shown in Table 10, this effect is positive but not significant (the coefficient is 1.2879, while the standard error is 2.4117), indicating that this cluster is not characterised by the emergence of 'hubs' or firms with an extraordinary number of out-going ties. This result is interesting and it is indeed consistent with the strengthening of a core-periphery structure of the knowledge network observed in Section 5.1.2. It suggests that it is a group of firms – and not simply a few of them – that become progressively more connected over time, an aspect that is in line with the transitivity effect found above.

Model 3 tests the effect of homophily of actors on new tie formation. Because parsimony is very important in this class of models, we dispose of the preferential attachment effect, which resulted not to be significant in Model 2. In Model 3 we test one dimension of homophily, which is the similarity in firms' knowledge base (KB) and find that it influences the formation of new ties as results are positive and significant – with a coefficient of 1.6021 and a standard error of 0.3644.

Table 10 Social Mechanisms underlying network change: an analysis using SIENA

	Model 1 Coeff (s.e.)	**Model 2** Coeff (s.e.)	**Model 3** Coeff (s.e.)
Rate Parameter	29.0871 (10.1500)	29.6887 (12.9691)	39.5910 (0.4127)
Network Effects:			
Density	-2.1848 (0.1660)	-2.3143 (0.4007)	-2.1043 (0.1848)
Reciprocity	2.5088 (0.2750)	2.5134 (0.3916)	2.1717 (0.2679)
Transitivity (Transitive triplets)	0.1732 (0.0304)	0.1602 (0.0351)	0.0993 (0.0287)
Preferential attachment (Activity of alter)		1.2879 (2.4117)	
Actors' effects:			
Homophily (KB similarity)			1.6021 (0.3644)

Note: Results of stochastic approximation. Estimated parameter based on 987 iterations. The convergence of the models was good in all cases (p<0.10 for all coefficients in all models) and no severe problems of multicollinearity were encountered.

5.3.2 The thresholding-effect

In this section, we explore whether there is a thresholding-effect with respect to firms' knowledge bases. Table 11 provides evidence to illuminate this aspect. In particular, it shows first that firms that are isolated at the intra-cluster level are those with the lowest average knowledge basescompared to firms occupying other cognitive positions in the same year. This result is found in both the 2002 and 2006 surveys (Table 11-a). Second, it shows that firms that are part of the periphery have on average lower knowledge bases than firms that are part of the core, a result that is found for both 2002 and 2006 (Table 11-b). Finally, it shows that firms that are isolated both at the intra- and extra-cluster levels (IF) have much weaker knowledge bases than TG and ES in both years (Table 11-c).

This evidence shows that firms with particularly weak knowledge bases are at best poorly connected to the intra-cluster knowledge network and tend to be disconnected from extra-cluster sources of knowledge. Interestingly enough, it shows that firms with weak knowledge bases do not form linkages among similar alters, given the fact that they are all part of a periphery with poor intra-periphery linkages. Hence, although this evidence does not *per se* represent a proof of the existence of a thresholding effect, it does at least provide strong evidence in favour of the fact that this factor can be important in explain lack of connectivity, and to explain the lack of effect of other social mechanisms.

Table 11: Exploring the threshold-effect of knowledge base in 2002 and 2006

	Average KB 2002	Average KB 2006
(a) Cognitive positions in the cluster		
Sources	1.00	0.40
Mutual Exchangers	0.65	0.47
Absorbers	0.07	-0.42
Isolates	**-0.88**	**-1.22**
(b) Cohesive subgroups		
Core	0.58	0.59
Periphery	**-0.45**	**-0.40**
(c) Key cognitive roles		
TG	0.86	0.73
ES	0.61	0.20
IF	**-0.70**	**-0.20**

Note (*): The values are calculated considering the network formed by the population of firms in each year.

Section 6 Conclusions

Scholars concerned with industrial clusters and networks have recently called for more research on network change over time. This paper makes a contribution along that path, being one of the few case studies to have collected longitudinal, small-scale survey (network) data in industrial clusters. This has been achieved through the execution of a pair of identical studies in the same wine cluster in Chile in 2002 and 2006. Using social network data, the paper explores the role of a set of mechanisms of social interaction to explain the change in the cluster knowledge network.

A particularly interesting finding is the coexistence of two results: first, the stability in the meso-level characteristics of the intra-cluster knowledge network, and second, a significant instability at the micro level. Stability at the meso-level is demonstrated by the fact that the distribution of knowledge linkages within the cluster did not change, while the core-periphery structure was reinforced. Considerable instability at the micro-level is reflected in the significant number of new ties that have been formed by firms over the four year period (observed in the higher density of the intra-cluster knowledge network in 2006). Also, a significant proportion of firms occupying imbalanced cognitive positions (absorbers and sources) have moved towards more balanced relations – a condition that also reflects the transitory nature of the firms with roles of External Stars. Finally, micro-level changes have also occurred in the population of firms, as six new firms, characterised by particularly strong knowledge bases, entered the cluster, while six firms with weak knowledge bases left .

From some perspectives this contrast might appear unexpected or even contradictory. We therefore review below some of the possible underlying reasons for the meso-level stability. First, mutual exchangers and technological gatekeepers demonstrated a strikingly persistent nature, providing support to the idea that reciprocity is an important driver of linkages' stability (Granovetter, 1985). Second, we found that firms in the core reinforced their central position at the intra-cluster level, intensifying relations with other core firms – a result that might be explained by the formation of ties between firms with similarly advanced knowledge bases (homophily) and by transitive closure. Third, isolated firms also turned out to be fairly persistent, at least to the degree that they did not exit the cluster. Those that remained in the cluster seem to have been subject to a 'thresholding' effect, which we have defined as the social exclusion of actors that are strikingly resource-poor – in this context the firms that had very weak knowledge bases. These firms have been inert, doing little or nothing to change their peripheral position in the intra-cluster knowledge network, thus contributing to its overall stability. Fourth, although a substantial share of firms occupying imbalanced cognitive positions (absorbers and sources) have become mutual exchangers, they have not significantly altered the core-periphery structure of the intra-cluster knowledge network – as reflected by the fact that the composition of the core has not varied substantially. Finally, although one might have expected the differences between the knowledge bases between entrants and exitors to have a significant influence on the structure of the knowledge network, this did not happen. The new firms did not immediately occupy central positions in the network within the time scope of this research. Instead, they occupied relatively peripheral positions, to a considerable extent replacing the old exitors.

The patterns observed here seem consistent with the idea of *retention* put forward by evolutionary economists to explain the path-dependent nature of economic systems in general (Nelson and Winter, 1982; Nelson and Winter, 2002) and networks in particular (Glückler, 2007). However, it goes beyond that by providing evidence about how social mechanisms of interaction may contribute to the combination of considerable instability at the micro-level and persisting stability in the structure of the knowledge network at the meso-level. This is an intriguing result and it opens up a range of further research questions. Some of these would pursue further the issues explored here about how micro-level mechanisms of social interaction relate to meso-level network structures. For example: what are the micro-level mechanisms of social interaction that are more likely to generate disruptive *vs* retention effects in networks? A second set of question is about whether and how this micro-meso relationship is mediated or influenced by 'institutional' issues (e.g. characteristics of firms, of the cluster, of the industry or technologies, etc.). For example: are social mechanisms of interaction more or less important than actor-level characteristics in explaining the retention of a network structure over time? Finally, given the importance attributed to the connection between clusters and global sources of knowledge, a set of issues about the external openness of the clusters merits further investigation. For example, how do micro-level mechanisms of social interaction *within* the cluster influence the way cluster firms connect to extra-cluster knowledge sources?

The analysis reported here was set within specific empirical and methodological limits. One is about the timescale of only four years between the observations. This means that we have almost certainly not been able to capture important changes that take longer to become manifest, perhaps because of learning and adjustment processes – for example the incorporation of new entrants into longer term positions in the network. This highlights the importance of designing much more of the research in this area in ways that permit more extended longitudinal perspectives.

A second limitation is that this is a single industry study covering a cluster of only 32 firms in a single Latin American country. This falls far short of the basis needed for even tentative speculations about policy. However, it raises questions that are relevant for policy. For example, how can policy-makers reinforce cluster development in contexts where (i) actors are highly heterogeneous, (ii) their interactions are strongly shaped by deeply embedded social processes, and (iii) the influence of entry/exit on cluster upgrading over the longer run may be just as great (or greater) than that of change in the behaviour of incumbents? Also, how in contexts involving highly unequal network structures, can they do so in inclusive ways that incorporate weak firms at the periphery of the knowledge network?

Acknowledgements

The authors would like to thank Roberta Rabellotti, Ron Boschma, Ron Martin, Martin Woerter, Dirk Fornahl, Johannes Glückler, Eric Stam, Andrea Morrison and the participants of the 2008 Workshop "Research Workshop: Networks in Society and the Economy" (University of Cambridge) and of the DRUID 2008 Summer Conference for helpful comments on previous versions of this paper. Special thanks go also to Cristian Diaz Bravo, Marcelo Lorca Navarro, Cristian Goich and the other enologos from Valle de Colchagua and to Mario Castillo and colleagues at CORFO. Funding provided by the EU Marie Curie Fellowship Program (HPMT-GH-00-00158-01), the UK Economic Social Research Council (ESRC) (PTA- 030200201739 and PTA- 026270644) and the Progetto Alfieri – Fondazione CRT (Italy) are gratefully acknowledged.

References

Amaral L.A.N, Scala A., Barthélémy M., Stanley H. E. 2000. Classes of small-world networks, *Applied Physical Sciences*, 97 (21), 11149-11152.

Arora A, Gambardella, A. 1990. Complementarity and external linkages: the strategies of the large firms in biotechnology. *The Journal of Industrial Economics* XXXVIII: 361-79.

Barabasi A-L, Albert R. 1999. Emergence of scaling in real networks. *Science* 286: 509-512.
Barabasi A-L., Albert R., Joeng H. 1999. Mean-field theory for scale-free random networks, *Physica A*, 272, 173-187.

Bell, M., Albu, M., 1999. Knowledge systems and technological dynamism in industrial clusters in developing countries. *World Development* 27 (9), 1715-1734.

Borgatti SP, Everett, MG, Freeman, LC. 2002. Ucinet 6 for Windows: Harvard: Analytic Technologies.

Borgatti, S.P., Everett, M.G., 1999. Models of core/periphery structures. *Social Networks* 21, 375-395.

Boschma, R. J. and Wal, A. L. J. Ter, 2007. Knowledge nerworks and innovative performance in an industrial district: The case of a footwear district in the south of Italy; *Industry and Innovation*, Vol 14, No. 2 (177-199)

Bouty I. 2000. Interpersonal and interaction influences on informal resource exchanges between R&D researchers across organizational boundaries. *Academy of Management Journal* 43: 50-65

Cantner, U. and Graf, H. 2006. The network of innovators in Jena: An application of social network analysis; *Research Policy*, Vol. 35 (463-480).

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly* 35, 128-153.

Cowan, R., Jonard, N. and Özman, M. 2004. Knowledge dynamics in a network industry; *Technological Forecasting and Social Change*, Vol 71 (469-484)

Ernst, D., Guerrieri, P., Iammarino, S. and Pietrobelli, C. 2001. New challenges for industrial clusters and districts: Global production networks and knowledge diffusion, in Guerrieri, P., Iammarino, S. and Pietrobelli, C. (Eds) *The global challenge to industrial districts: small and medium-sized enterprises on Italy and Taiwan*, Edward Elgar, Cheltenham.

Fehr, E. and Gachter, S. 2000. Fairness and Retaliation: The Economics of Reciprocity, *The Journal of Economic Perspectives*, 14 (3), Summer, 159-181.

Fleming, L. and Frenken, K. 2007. The evolution of inventor networks in the Silicon Valley and Boston regions; *Advances in Complex Systems*, Vol. 19 (53-71)

Gibbons D., Olk G. 2003. Individual and structural original of friendship and social position among professionals, *Journal of Personality and Social Psychology*, 84 (2), 340-351.

Giuliani E. 2007. The selective nature of knowledge networks in clusters: evidence from the wine industry, *Journal of Economic Geography* 7: 139-168.

Giuliani E. (2005) When the micro shapes the meso: learning and innovation in wine clusters. Unpublished DPhil Thesis, SPRU: University of Sussex, Brighton, UK.

Giuliani E., Bell M. 2005. The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster, *Research Policy*, 34(1), 47-68.

Granovetter M. 1978. Threshold models of collective behavior. *American Journal of Sociology*, 83(6), 1420-1443.

Glückler, J. 2007. Economic geography and the evolution of networks; *Journal of Economic Geography*, Vol. 7, 5; 619 –635.

Goh K-Il, Oh E., Jeong H., Kahng B., Kim D. 2001. Classification of scale free networks, *Physics*, 99 (20), p. 12583-12588

Gouldner A.W., 1960. The norm of reciprocity: A preliminary statement, *American Sociological Review*, 25 (2), 161-178.

Granovetter M. 1985. Economic action and social structure: the problem of embeddedness. *American Journal of Sociology* 91: 481-510.

Griliches Z. 1992. The search for R&D spillovers. *Scandinavian Journal of Economics* 94: 29-47.

Guerrieri, P. and Pietrobelli, C. 2001. Models of industrial clusters' evolution and changes in technological regimes, in Guerrieri, P., Iammarino, S. and Pietrobelli, C. (Eds) *The global challenge to industrial districts: small and medium-sized enterprises on Italy and Taiwan*, Edward Elgar, Cheltenham.

Hamel G. 1991: Competition for competence and interpartner learning within international strategic alliances. *Strategic Management Journal* 12: 83-103.

Heider, F. (1958) *The psychology of interpersonal relations*, New York: Wiley

Hersberger, J.A. (2007). Extreme Disruptions of Egocentric Social Networks: Information Consequences and Affective Outcomes. Sunbelt XXVII, May 3, Corfu, Greece

Holland, P.W., Leinhardt, S., 1971. Transitivity in structural models of small groups. *Comparative Group Studies* 2, 107–124.

Iammarino, S. and McCann, P. 2006. The structure and evolution of industrial clusters: Transactions, technology and knowledge spillovers; *Research Policy*, Vol. 35 (1018-1036)

Lane PJ, Lubatkin, M. 1998. Relative absorptive capacity and interorganizational learning. *Strategic Management Journal* 19: 461-77.

Lazarsfeld, P., and R. K. Merton. (1954). Friendship as a Social Process: A Substantive and Methodological Analysis. In *Freedom and Control in Modern Society*, Morroe Berger, Theodore Abel, and Charles H. Page, eds. New York: Van Nostrand, 18-66.

Louch H. 2000. Personal network integration: transitivity and homophily in strong-tie relations. *Social Networks* 22: 45-64.

Markusen, A. 1996. Sticky places in slippery space: A typology of industrial districts. *Economic Geography*, 72(3): 293-313.

Masuda N., Konno N. 2006, VIP-club phenomenon: Emergence of elites and masterminds in social networks, *Social Networks,* 28, 297-309.

McPherson M, Smith-Lovin, L. 1987. Homophily in voluntary organizations: status distance and the composition of face-to-face groups. American Sociological Review 52: 370-9.

McPherson, M., Smith-Lovin, L., Cook, J. M., 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology*, 27, 415-444.

Mowery DC, Oxley, JE, Silverman, BS. 1996. Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal* 17: 77-91.

Mowery DC, Oxley, JE, Silverman, BS. 1998. Technological overlap and interfirm cooperation: implications for the resource-based view of the firm. *Research Policy* 27: 507-23.

Morrison A., Rabellotti R., 2005, , Knowledge dissemination and informal contacts in an Italian wine local system, PRIN Working Papers 1, Dipartimento di Scienze Economiche, Bologna University, Bologna.

Nelson RR, Winter, SG. 1982. An Evolutionary Theory of Economic Change. Cambridge, Mass: Belknap Press of Harvard University Press.

Nelson, R. R. and Winter, S. G. (2002) Evolutionary theorizing in economics, *Journal of Economic Perspectives*, 16, 23–46.

Powell, W. W., White, D. R., Koput, K. W. and Owen-Smith, J. 2005. Network dynamics and field evolution: The growth of interorganizational collaboration in the life science; *American Journal of Sociology*, 110 (January), 1132-1205.

Rogers EM. 1983. *Diffusion of Innovations*. New York: The Free Press.

Rokach, A. 2004. Loneliness then and now: Reflections on social and emotional alienation in everyday life. *Current Psychology*, 23, 24–40

Schrader S. 1991. Informal technology transfer between firms: cooperation through informal trading. *Research Policy* 20, 153-70.

Snijders, T.A.B., Ch. Steglich, M. Schweinberger and M. Huisman. 2005. Manual for

SIENA version 2.1. University of Groningen: ICS / Department of Sociology.

Snijders, T.A.B. 2001. The statistical evaluation of social network dynamics. Pp. 361-395 in Sociological Methodology – 2001, edited by M.E. Sobel and M.P. Becker. Boston and London: Basil Blackwell.

Steglich C., Snijders T.A.B., West P. 2007 Applying SIENA: An illustrative analysis of the co-evolution of adolescents' friendship networks, taste in music, and alcohol consumption, http://www.gmw.rug.nl/~steglich/pdf/SteglichSnijdersWest.pdf.

Trivers R.L. 1971. The evolution of reciprocal altruism, *The Quarterly Review of Biology*, 46 (1), 35-57.

UNIDO, 2004. *Industrial clusters and poverty reduction*, UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, Vienna. http://www.unido.org/fileadmin/import/24692_Clustersandpoverty.pdf

Uzzi, B. and Spiro, J. 2005. Collaboration and creativity: The Small World problem, *American Journal of Sociology*, Vol. 111, N0. 2 (447-504).

Valente T. W. 1996. Social network thresholds in the diffusion of innovations. *Social Networks*, 18, 69-89.

Visser E-J. 1999. A comparison of clustered and dispersed firms in the small-scale clothing industry of Lima. *World Development* 27: 1553-70.

von Hippel E. 1987. Cooperation between rivals: informal know-how trading. *Research Policy* 16: 291-302.

Wal, A. L. J. Ter and Boschma, R. J. 2007. Co-evolution of firms, industries and networks in space; Papers in Evolutionary Economic Geography # 07.07; Urban and Regional Research centre, Utrech University.

Wasserman S, Faust, K. 1994. *Social Network Analysis. Methods and Applications.* Cambridge: Cambridge University Press.